WINONAITES REVISITED: NEW INSIGHTS INTO THEIR FORMATION

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Introduction The winonaites are primitive achondrites that experienced limited partial melting and show evidence for brecciation and metamorphism on the precursor body. We have previously presented results of a preliminary study of the winonaites and insights into their formation[1]. With the recent identification of new winonaites [2-5] and the availability of new thin sections of previously studied winonaites, we have revisited the winonaites to shed new light on their formation. We now have a better understanding of the nature of the precursor material as well as the processes which affected it. The precursor body was likely chondritic, but unlike any known chondrite group. Heating and partial melting, mixing, and metamorphism and cooling altered the precursor. Peak temperatures were reached before brecciation, but some metamorphism and reduction also took place after brecciation. ^{39}Ar-^{40}Ar age determinations and cosmogenic and measurements of trapped noble gases for Pontlyfni, Winona, and Mt. Morris (Wis.) [6] are consistent with the parent body history outlined here.

New Results In addition to the previously defined members of the group [1], three Antarctic meteorites (QUE 94535, Y-8005, Y-75261) have recently been classified as winonaites on the basis of chemical and oxygen isotopic compositions [2-5]. We have studied one of these, QUE 94535, and some new thin sections of Pontlyfni. Pontlyfni does not exhibit the equilibrated textures characteristic of Winona and the other winonaites [1]. Its texture is more similar to type 6 chondrites, exhibiting widely varying grain sizes, textures, and mineralogy. We also have found relict porphyritic and radiating pyroxene chondrules in Pontlyfni, which have not been reported before. In addition, veins of Fe,Ni metal and FeS are prominent. Pontlyfni also contains a small (< 500 µm) plagioclase-calcic pyroxene-rich area that suggests in situ limited partial melting of plagioclase-pyroxene (i.e. “basaltic” partial melting). QUE 94535 is similar to Pontlyfni in grain size and texture, but does not have the plagioclase-rich areas. It is also slightly recrystallized compared to Pontlyfni, making QUE 94535 transitional between Pontlyfni and Winona in texture.

Reported data for new members extend the range of mineral compositions in the winonaite group. QUE 94535 [2] and Y-8005 [3] have mineral compositions which fall in the previously recognized range ($Fa_{0.7-5.3}$, $Fs_{0.5-8.3}$) [1], but Y-75261 has even more reduced mineral compositions ($Fa_{0.3}$, $Fs_{0.3}$) [5]. Modal analyses (both old and new) indicate a correlation between the mineralogy and mineral compositions. Winonaites with more reduced mineral compositions (lower FeO) contain reduced accessory minerals such as daubreelite, while winonaites with minerals containing more FeO contain oxidized accessory minerals such as chromite.

Nature of the precursor body From these new studies on winonaites, specifically Pontlyfni, inferences about the nature of the precursor material can be made. One is that the precursor was likely chondritic, as suggested by the roughly chondritic bulk chemical compositions and mineralogy, as well as the presence of relict chondrules in Pontlyfni [this work] and Mt. Morris (Wis.) [1]. However, the mineral compositions of the winonaites are intermediate between E and H chondrites and the oxygen isotopic compositions of the winonaites are unlike any group of known chondrites [7].

We suggest that winonaites may have formed from heterogeneous chondritic precursors. Although there is no correlation between mineral (Fa, Fs) and oxygen isotopic compositions which is indicative of primary heterogeneity [8, 9], a correlation between mineral compositions and mineralogy does exist. This correlation could be produced by reduction due to metamorphism, but as discussed below, the differences in mineralogy are more easily explained by compositional heterogeneity in the precursor chondritic material.

Heating and Partial melting. In addition to the coarse-grained olivine-rich clumps found in Winona and Mt. Morris (Wis.) [1], evidence for both Fe,Ni-FeS and silicate partial melting is present in Pontlyfni. This evidence includes the veins of Fe,Ni metal and FeS, as well as the plagioclase-calcic pyroxene-rich area. The fact that the area is so small probably indicates that melting was limited and melt migration distances were very short. Finally, in our preliminary study, we suggested that the large poikilitic calcic-pyroxene grains found in Tierra Blanca were indicative of trapped partial melt. Newly produced elemental (Mg and Al) maps show an absence of melted plagioclase associated with the calcic pyroxene. This indicates that the poikilitic grains probably formed by solid state growth and reaction during metamorphism, as argued by [10].

Mixing Winonaites exhibit evidence for brecciation. One feature indicative of brecciation is the coarse-grained olivine-rich clumps found in Winona and Mt. Morris (Wis.) [1]. Another is the boundary between two lithologies found in Y-75300. The borders between the different lithologies found in these meteorites are distinct, but not sharp. From the evidence that various lithologies experienced partial melting and some metamorphism (grain size differences) prior to mixing, brecciation must have occurred after peak temperatures had been reached.

Metamorphism and cooling Although we break up the processes involved in the formation of the winonaites into three separate stages, we recognize that heating and cooling was a continuous process interrupted by one or more episodes of impact and brecciation. Evidence for metamorphism includes equigranular textures, abundant 120° triple junctions, grain size variations, and reduction in mafic minerals. In addition to the recrystallized textures and overall coarsening of grains, formation of the large poikilitic calcic pyroxene grains in Tierra Blanca is attributed to metamorphism [10].

The ranges of mineral compositions is due, at least in part, to reduction due to metamorphism. Olivine Fa values are generally lower than Fs in low-Ca pyroxene, which is indicative of solid state reduction during cooling. In addition, Tierra Blanca olivines and low-Ca pyroxene grains enclosed in the poikilitic calcic pyroxenes are less reduced than the same minerals found in the matrix, suggesting the poikilitic calcic pyroxene may act as a barrier to diffusion. Despite these indications of reduction in individual winonaites, it seems unlikely that the full range of mineral compositions and mineralogy observed in winonaites can be attributed solely to variable levels of reduction of a common precursor. One indication of this is the distribution of winonaite compositions on a plot of Fa vs. Fs (Fig. 1). If the range of mineral compositions formed by reduction of a common precursor, we would expect to see a curved trend (hatched line), because diffusive reduction of FeO occurs more rapidly in olivine than low-Ca pyroxene. Instead, we observe a nearly linear trend. This, coupled with the correlation between mineralogy and mineral compositions discussed above, is more easily explained by primary heterogeneity in the precursor body.

^{39}Ar-^{40}Ar ages ^{39}Ar-^{40}Ar ages have been measured for three winonaites: Pontlyfni, Winona, and Mt. Morris (Wis.) [6]. Cosmogenic and trapped noble gas abundances have also been measured. The results will be discussed in a separate talk. The history of the winonaite body laid out here is consistent with the measured ^{39}Ar-^{40}Ar ages.

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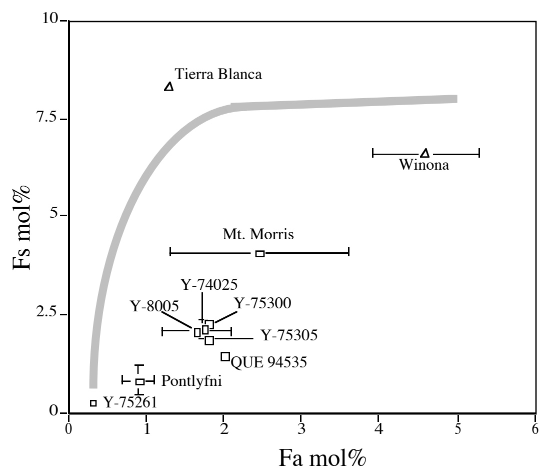

Figure 1. Fa in olivine vs Fs in low-Ca pyroxene in the winonaites. Reduction due to diffusion of a common precursor would produce a curved trend (hatched line) on the plot. We observe a linear trend which we interpret to be due to primary heterogeneity in the precursor chondrite. Symbols indicate the presence of the primary accessory mineral: squares for daubreélite; triangles for chromite. Bars illustrate ranges in average Fa and Fs reported by different investigators for individual winonaites.